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Summary and Recommendations for Initial Exercise Prescription

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Introduction

Designing the exercise countermeasure facility for use on board the U.S. Space Station will be a challenging task for NASA life sciences personnel and the outside community. During the next decade, there will be a transition within the U.S. space program to longer duration space flight. The role of exercise countermeasures in supporting men and women in this operational environment will become exceedingly important and complex. Although most concede that an exercise program of some fashion will be necessary, there is no clear consensus on the type, frequency, duration, or intensity of exercise, nor has the in-flight equipment to be used been accurately identified.

The responsibility for the design of the Space Station exercise countermeasure facility and for the operational objectives resides with NASA physicians and scientists. The exercise countermeasure facility is one of the three subsystems of the crew health care subsystem (CHECS), which additionally includes the health maintenance facility and the environmental health subsystem. The CHECS is designed to provide on-board preventive and medical care for the Space Station crew.

The purpose of the 1986 conference, "Exercise Prescription for Long-Duration Space Flight," was to assemble both NASA scientists and members of the academic community to discuss the development of an exercise prescription and the exercise modalities for use on the Space Station. It is anticipated that the results of this conference could contribute to the preliminary formulation of the Space Station exercise prescription. This prescription will be modified as indicated by future discussion, by ground-based research activities, and, ultimately, by the results of an

in-flight effort to validate the operational prescription.

The rationale for the development of an exercise prescription for long-duration space flight is based on operational and medical requirements designed to adequately address health concerns of the crew. The following operational requirements for exercise countermeasures were established.

- Preserve the appropriate level of aerobic capacity and muscular strength/endurance to facilitate crewmembers' ability to perform demanding physical work required on board Space Station, such as repetitive extravehicular activities (EVA's).
- Maintain the integrity of the musculoskeletal system to prevent or minimize risk of injuries resulting from atrophy of bones, tendons, or ligaments.
- Maintain general physical fitness as it benefits the individual's health and sense of well-being.
- Sustain the ability to accomplish an end-of-mission unaided egress.
- Minimize the time required for postmission reconditioning.

Medical requirements for exercise countermeasures were as follows.

- Prevent muscle atrophy, reduction in muscle volume, loss of strength, and decline in functional capacity.
- Prevent cardiovascular deconditioning, decrease in fluid volume, increase of vascular compliance, and orthostatic intolerance.
- Prevent or retard bone demineralization, loss of bone integrity and strength, and the development of hypercalciuria, renal stones, and hypercalcemia.

Formulation of an Exercise Prescription

The design of an exercise prescription for space flight must follow certain parameters for development; i.e., specificity, mode, duration, intensity, frequency, and progression of physical activity (ref. 1). In addition, to meet the operational and medical requirements, there are other significant factors which must be addressed. First, the basic physiology of exercise in respect to one g and the adaptation to zero g must be delineated. The prescription must adequately address the physiologic adaptations to microgravity. Second, the nature of Space Station crew activities must be defined, and the exercise protocols and prescriptions must be incorporated within these activities. Current understanding of these activities is that at least two crewmembers will need to exercise during the same time period. Third, periodic evaluation of the crewmembers' physical condition will need to be conducted in flight to assess effectiveness of the prescriptions. Last, functional in-flight hardware for exercising must be developed.

Summary of Comments and Recommendations by Working Groups

To facilitate discussion on the design of an exercise prescription at the conference, all participants were assigned to a working group. The following is a summary of the conclusions of each group and their overall recommendation.

A. Cardiovascular Working Group

- As a primary goal, the group recommended that the exercise protocols be capable of maintaining a level of systemic oxygen transport which is comparable to an individual's preflight, upright baseline.
- Preflight fitness level should be quantified by measurement of maximal oxygen uptake on at least three occasions over several months in the preflight period.
- The minimum time dedicated to cardiorespiratory fitness is four sessions per week at an intensity level of 70 to 80 percent of preflight maximum oxygen uptake $\text{VO}_2 \text{ max}$.
- At least one exercise session per week, including measurements such as the heart-rate/workload or heart-rate/oxygen-uptake relationship, should be monitored. Respiratory gas analysis was recommended.

- It was strongly recommended that the exercise system "start out with an effective system for collection and evaluation of the physiologic characteristics and effects of any exercise program."

- The principal component of the in-flight cardiovascular exercise program should be a large-muscle activity exercise such as a treadmill.

B. Muscle Working Group

- Two different components for an exercise program were identified, one intended to target individuals tasked with performing EVA's, and a second component designed to target the antigravitational muscles, to be performed by all crewmembers.

- To maintain the strength and endurance of the upper arms, a minimum of 30 to 40 minutes per session, three to four times per week, was recommended.

- Specific recommendations were not given with regard to an amount of time allotted for prevention of muscle atrophy of the antigravitational musculature.

- It was recommended that the exercise prescription be designed to train individuals for optimal in-flight productivity, with an acceptable safety margin for human error.

- Recommendations specific to EVA were as follows.

- A space suit should be instrumented so as to analyze movements with respect to displacement/forces for both hand movements and movements of the elbow and the shoulder.

- An instrumented suit could be used for practice of specific movements and for endurance training.

- Preflight training of the upper body musculature should be conducted for missions with frequent EVA's.

- General consensus of the group was that atrophy of the muscles should be minimized, but that complete maintenance of muscle mass may not be required. It was recommended that an analysis of the tradeoff between time required and maintenance of muscle function be accomplished.

- Several exercise modalities were suggested.

- For maintenance of general antigravitational musculature, a treadmill and a rowing machine were endorsed.

- For training of specific joints, a device capable of controlling and recording muscle shortening and lengthening velocities and forces was recommended.

- A jumping apparatus was mentioned as a way to produce higher power efforts with concomitant recruitment of motor units with higher thresholds.

- With regard to research required to further define exercise modalities for maintenance of muscle function, bed-rest studies were recommended as an important resource, and analysis of muscle biopsies are needed to test the hypotheses supporting the various recommendations.

C. Skeletal Working Group

- It was recommended that a countermeasure be employed to prevent and/or minimize the previously observed changes in the skeletal system during flights of 90 to 180 days.

- It was recommended that Space Station be used as an operational testbed for longer interplanetary missions planned for the future.

- With regard to a specific countermeasure for treatment of bone loss, it was recommended that the measure employed be capable of replacing the locomotor activity absent in the microgravity environment. Critical activities in this regard include the force/time profiles seen in the lower extremity and vigorous eccentric muscle action.

- It was the recommendation of the group that a treadmill could be used as the primary device to provide locomotor forces to the lower extremity.

- It was suggested that an exercise program should be compulsory for all crewmembers, and that the prescription should be individualized.

- A strong recommendation was made that NASA collect and maintain an epidemiological data base on members of the astronaut corps from time of selection onward.

- A number of recommendations were made regarding the need for research activities to support design of a bone countermeasure, including the following.

- Additional studies need to be done to identify potential effects of increased calcium mobilization.

- Studies to elucidate the effects of various types of exercise activities during bed rest need to be accomplished, and the dose/response of the exercise should be established.

- The effects of different types of forces on various parameters in calcium kinetics need to be demonstrated.

- Studies should be done on individuals at both extremes of calcium turnover in order to maximize the success of various experiments.

- Recovery kinetics of bone loss need to be characterized.

- Various areas of bone need to be evaluated with densitometry rather than measuring the changes only in the calcaneus and extrapolating.

- A specific recommendation was not made with regard to the amount of time needed for a bone countermeasure. It was recommended that this activity be done on a daily basis.

Conclusion

The recommendations summarized herein constitute a basis on which an initial exercise prescription can be formulated. It is noteworthy that any exercise program designed currently would be an approximation. Examination of the existing space-flight data reveals a scarcity of in-flight data on which to rigorously design an exercise program. The relevant experience within the U.S. space program (with regard to long-duration space flight) is limited to the Skylab Program. Lessons learned from Skylab are relevant to the design of a Space Station exercise program, especially with regard to the total length of exercise time required, cardiovascular (CV) deconditioning/reconditioning, and bone loss. Certain observations of the U.S.S.R. exercise activities can also contribute to the formulation of an exercise prescription for Space Station (ref. 2). Reportedly, the U.S.S.R. uses both a bicycle ergometer and a treadmill device on long-duration missions with some degree of success. Using the third crew of Salyut 6, which was a 175-day stay, as a representative mission, the typical time dedicated to exercise varies from 2 to 3 hours per day. In addition, the cosmonauts wear an elasticized suit, called a penguin suit, for time periods ranging from 12 to 16 hours per day. This device provides a load across the axial skeleton against which the wearer must exert himself. Despite these extensive countermeasures, the effects of adaptation are not totally prevented.

Proposed Exercise Prescription

The following proposed prescription is intended to incorporate the recommendations of the exercise conference working groups and the

operational and medical requirements. Table I is the proposed exercise prescription, which reflects the difference between the EVA crewmember and the non-EVA crewmember. Additionally, figure 1 indicates how the proposed prescription could be scheduled to accommodate two exercising crewmembers. It is recognized that the following provides only a structure upon which individualization of crewmember protocols could be developed.

Discussion

The prescription as outlined incorporates the general recommendations put forth by the participants of this meeting. There are still many questions on the intensity, the duration, and the specificity of exercise which must be addressed during the years preceding permanent manned presence (PMP) of the Space Station.

TABLE I.- PROPOSED EXERCISE PRESCRIPTION

Day	Exercise prescription for -			
	EVA crewmember		Non-EVA crewmember	
	Mode and apparatus (a)	Duration, min	Mode and apparatus (a)	Duration, min
1	M1 ^b TM BE	30 30 20	M1 TM R/BE	20 30 (c)
2	M2 ^d TM R	30 30 20	M2 TM R/BE	20 30 20
3	M1 TM BE	30 30 20	M1 TM R/BE	20 30 (c)
4	M2 TM R	30 30 20	M2 TM R/BE	20 30 20
5	M1 TM BE	30 30 20	M1 TM R/BE	20 30 (c)
6	M2 TM R	30 30 20	M2 TM R/BE	20 30 20
7	(c)	(c)	(c)	(c)

^aTreadmill (TM), bicycle ergometer (BE), and rower (R) exercise performed at approximately 75 percent of preflight maximum oxygen uptake.

^bM1 = upper body muscle training.

^cOptional.

^dM2 = lower body muscle training.

		Exercise					
	Pre-exercise	Period 1 (aerobic)	Cooldown	Rest	Period 2 (anaerobic)	Cooldown	Post-exercise
Time, min	20	30	5	10	30	5	20

Modes: treadmill, cycle ergometer, rower, and resistive exerciser

Fig. 1.- Proposed exercise regimen.

The development of any exercise prescription must include consideration of the exercise habits and the in-flight duties of each individual crewmember. The basic goal for any exercise countermeasure program will be to maintain preflight levels of function. The emphasis will be on maintaining a degree of overall fitness and musculoskeletal conditioning which is compatible with both in-flight and postflight operational and medical objectives.

The formulation of a separate exercise prescription for designated EVA crewmembers as suggested was based on the following considerations. As suggested by both Convertino and Moore, EVA tends to be more of an activity requiring sustained submaximal aerobic performance than one requiring frequent use of peak aerobic power. A reasonable characterization would be that of sustained low-level work with infrequent short periods of nearly maximal (aerobic) effort. Therefore, the operationally driven requirement for aerobic fitness in EVA crewmembers would be primarily for endurance rather than sustained peak aerobic performance. The suggested EVA crewmember exercise protocol would require between 45 and 60 minutes per day of aerobic exercise, an adequate amount of time to maintain cardiorespiratory fitness in individuals with a $\text{VO}_2 \text{ max}$ of 40 to 60 ml/kg/min. The requirement for the non-EVA crewmember is 30 minutes per day, which is adequate to maintain the levels of aerobic fitness

typically seen in the astronaut corps. (Average $\text{VO}_2 \text{ max}$ for the astronaut corps is around 45 ml/kg/min.) These times are based on the assumption that maximal aerobic capability can be maintained in the microgravity environment with "one-g equivalent" times, which has not yet been proven.

A second requirement unique to designated EVA crewmembers pertains to muscle strength and endurance. Although detailed studies to elucidate the biomechanical nature of EVA have not been documented, the activity has been generally characterized as one requiring primarily upper body fitness. Most of the tasks accomplished during EVA require extensive use of the upper extremities, which in effect requires the crewmember to perform simultaneously his specific task as well as those needed for position stabilization and for counteracting the tendency of the pressure suit to assume a neutral position at the joints. Time has been allotted in the EVA crewmembers' exercise prescription to allow for additional upper extremity training and an emphasis on total-body exercise.

It is anticipated that the nature of the proposed exercise prescription should become more accurate as the subsequent research activities are conducted prior to PMP. As made apparent by comments during the meeting, there is considerable variation across discipline areas with regard to the amount of data available to support design of a

particular protocol. The recommendations offered by the CV and muscle groups were more concrete than those put forth by the skeletal group. The general lack of knowledge regarding the nature of force profiles needed to maintain bone integrity (both in one g and in microgravity) may necessitate a more empiric approach to the design of the bone countermeasure for Space Station. Optimally, well-designed scientific studies will adequately address these concerns before Space Station is assembled on orbit. This exercise workshop has set the foundation from which further ground-based and in-flight studies will validate the individualized Space Station exercise prescriptions.

References

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